The Effect of Sit-To-Stand and Heel-Raise Exercises on Dynamic Balance Function in Sedentary Male Adolescents

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ABSTRACT

Objective: To evaluate the effect of combined sit-to-stand and heel-raise (STS-HR) exercises on dynamic balance function in sedentary male adolescents.

Materials and Methods: A randomized controlled trial with a pretest–posttest design was conducted involving 30 sedentary male adolescents, randomly allocated into a control group (n = 15) and an intervention group (n = 15). The intervention group performed STS-HR exercises three times per week for 8 weeks. Dynamic balance was assessed using the Y-Balance Test (YBT), with composite reach length (CRL) of both limbs as the primary outcome.

Results: No significant changes were observed in the control group across all YBT directions ($p > 0.05$). In contrast, the intervention group demonstrated significant improvements in anterior, posterolateral, and posteromedial reach directions, as well as CRL values for both limbs ($p < 0.001$). After adjustment for baseline bilateral composite score and caloric intake, the bilateral mean composite Y-Balance Test score at week 8 was 12.4 percentage points higher in the STS-HR group than in the control group (95% CI 8.6–16.1; $p < 0.001$; partial $\eta^2 = 0.642$).

Conclusion: Among sedentary male adolescents, the 8-week STS-HR program improved week-8 Y-Balance Test performance compared with the control condition. The clinical importance and longer-term functional implications of this improvement remain uncertain.

Keywords: Adolescents; sedentary lifestyle; sit-to-stand; heel-raise; dynamic balance (Siriraj Med J 2026;78(9):709-722)

INTRODUCTION

Adolescence represents a critical developmental window that shapes long-term health trajectories. Globally, individuals aged 10–24 years account for nearly a quarter of the population, making this group a strategic target for preventive health interventions. Investments in adolescent health are known to yield a "triple dividend", benefiting current well-being, future adult health, and even the next generation.[1,2] Despite being generally perceived as a healthy phase of life, many non-communicable diseases (NCDs) in adulthood originate from modifiable risk behaviors established during adolescence, particularly physical inactivity and sedentary lifestyles.[3]

In recent decades, sedentary behavior has emerged as a dominant lifestyle pattern among adolescents. The rapid expansion of digital technology has shifted daily activities toward prolonged sitting, including screen-based entertainment and academic tasks. Alarmingly, more than 80% of adolescents worldwide fail to meet recommended physical activity levels.[4] This prevalence is even higher in Southeast Asia, reaching 73.4%, and in Indonesia, where it has increased from 83.6% in 2007 to 87.1% in 2015.[5] Such behavioral shifts have profound implications for physical fitness, neuromuscular function, and overall motor development. Among these, dynamic balance, a key component of functional movement and injury prevention, appears particularly vulnerable to reduced physical activity.

Dynamic balance plays a central role in maintaining postural stability during movement and is an essential component of fundamental motor skills (FMS). Adequate development of FMS during adolescence is strongly associated with higher levels of physical activity, better metabolic health, and improved motor competence.[6,7] Conversely, insufficient motor skill development contributes to a cycle of inactivity and declining physical function. Empirical evidence indicates that adolescents with sedentary lifestyles exhibit poorer dynamic balance, increasing their risk of falls, postural abnormalities, and reduced functional capacity in daily activities.[8,9]

From a physiological perspective, prolonged sedentary behavior is associated with reduced muscle strength, impaired neuromuscular coordination, and altered biomechanical alignment. These changes are often accompanied by increased adiposity and decreased lean muscle mass, both of which negatively affect postural control and stability.[10–12] Furthermore, the concept of Exercise Deficit Disorder (EDD) highlights a growing concern that many adolescents fail to achieve the minimum level of physical activity required for optimal musculoskeletal and neuromotor development, potentially leading to long-term health consequences.[13]

Given this context, effective and practical interventions are needed to improve neuromuscular function and dynamic balance in sedentary adolescents. Functional exercises have gained increasing attention due to their ability to mimic daily movements and simultaneously enhance strength, coordination, and motor control. Among these, the sit-to-stand (STS) exercise is widely recognized for its effectiveness in strengthening lower limb muscles and improving functional mobility across various populations.[6,14–16] However, evidence regarding

its impact on balance outcomes remains inconsistent, suggesting that STS alone may not be sufficient to optimize postural control.[17]

To address this limitation, combining STS with heel-raise (HR) exercises may offer a more comprehensive approach. While STS primarily targets major muscle groups such as the quadriceps and gluteal muscles, heel-raise exercises specifically activate the plantar-flexor muscles, including the gastrocnemius and soleus, which are crucial for postural stability and balance control. Previous studies have shown that heel-raise training can increase soleus muscle thickness and plantar-flexor strength, contributing significantly to improved postural control.[18] Additionally, such combined functional movements may enhance proprioceptive input and neuromuscular coordination, both of which are essential for maintaining dynamic stability.[19–21]

Despite these promising theoretical advantages, empirical evidence examining the combined effects of sit-to-stand and heel-raise exercises on dynamic balance in sedentary adolescents remains limited. Most existing studies focus on isolated interventions or adult populations, with little attention to integrated functional training approaches in adolescents. This gap highlights the need for targeted research to evaluate whether such combined exercises can effectively improve balance outcomes in this population.

Therefore, this study aims to investigate the effect of sit-to-stand and heel-raise exercises on dynamic balance function in sedentary male adolescents. By addressing this gap, the study contributes to the growing literature on adolescent motor development and offers a simple, low-cost, and scalable intervention that can be implemented in school or community settings to promote physical health and prevent future functional decline.

MATERIALS AND METHODS

This study employed a randomized single-blind controlled trial with a two-group pretest–posttest design. Participants were randomly allocated into an intervention group and a control group. Dynamic balance was assessed at baseline and after the intervention period using the Y-Balance Test. Outcome assessment was conducted by five independents, trained healthcare assessor who was blinded to group allocation.

The study was conducted between February and October 2025 at a senior high school in Surabaya, Indonesia. All exercise interventions and assessments were performed within the school environment under supervised conditions. The study population consisted of male adolescents aged 15–17 years. Permission to conduct the study was obtained from the school principal before participant recruitment. Eligible participants were identified through an initial screening process. Students who met the criteria for sedentary behavior based on the International Physical Activity Questionnaire (IPAQ) and demonstrated adequate baseline static balance (one-leg stance >10 seconds) were invited to participate. Recruitment was voluntary, and no financial incentives were provided. Because all participants were minors, written informed consent was obtained from their parents or legal guardians, while written assent was obtained from each participant before enrollment. Participants were informed that they could withdraw from the study at any time without any academic or personal consequences.

Physical activity was assessed using the International Physical Activity Questionnaire–Long Form (IPAQ-LF), which records the frequency (days/week) and duration (minutes/day) of physical activity performed during the previous seven days across four activity domains: work-related activity, transportation, domestic and household activity, and recreation, sport, and leisure-time activity. Sitting time was recorded separately. Following the IPAQ scoring protocol, walking, moderate-intensity activity, and vigorous-intensity activity were assigned metabolic equivalent values and expressed as MET-min/week. Domain-specific scores were calculated as the assigned MET value multiplied by the duration in minutes and frequency in days, and the total physical activity score was calculated by summing the scores across all domains. Participants were categorized as having low, moderate, or high physical activity levels according to the established IPAQ criteria. For this study, only participants classified in the low physical activity category. Moderate physical activity was defined as meeting at least one of the following criteria: (1) vigorous-intensity activity on at least 3 days for at least 20 minutes/day; (2) moderate-intensity activity and/or walking on at least 5 days for at least 30 minutes/day; or (3) any combination of walking, moderate-intensity activity, and vigorous-intensity activity on at least 5 days achieving a minimum total physical activity of 600 MET-min/week. High physical activity was defined as either: (1) vigorous-intensity activity on at least 3 days achieving at least 1,500 MET-min/week; or (2) any combination of walking, moderate-intensity activity, and vigorous-intensity activity on 7 days achieving at least 3,000 MET-min/week. Participants who did not meet the criteria for either category were classified as having low physical activity. In accordance with the standard IPAQ scoring protocol, walking, moderate-intensity activity, and vigorous-intensity activity were assigned values of

3.3, 4.0, and 8.0 METs, respectively. Exclusion criteria included a history of musculoskeletal, neurological, cardiovascular, or other medical conditions that could affect participation or outcomes. Participants who missed more than 20% of training sessions or withdrew consent were classified as dropouts.

The sample-size calculation used the formula

$$n1 = n2 = \frac{2SD^2\,(Z1/2\alpha+Z\beta)^2}{(X_1-X_2)}$$

The previous study reported mean scores of 89.46 group 1 and 96.26 group 2, corresponding to an expected mean change of 6.80 points. Using an estimated variance of 53.86 (standard deviation, 7.34). With a two-sided α of 0.05 (1.96) and 80% power (0.84). The estimated minimum sample size was 9.13, which was rounded up to 10 participants per group. After adding a 20% allowance for attrition, the recruitment target was set at 12 participants per group. Thirty eligible participants were ultimately enrolled and allocated equally, resulting in 15 participants per group. The decision to enroll all 30 eligible participants was made before randomization and before the investigators examined any outcome data.

Participants were allocated in a 1:1 ratio to the STS-HR intervention or control group using simple randomization. After all participants had been enrolled and assigned unique identification numbers, a researcher generated random numbers using the RAND() function in Microsoft Excel and sorted the identification numbers according to the generated values. The first 15 participants in the randomized sequence were allocated to the intervention group and the remaining 15 to the control group. No block randomization or stratification was used.

The intervention group participated in a supervised combined sit-to-stand and heel-raise (STS-HR) exercise program three times per week for 8 consecutive weeks. The intervention was developed with reference to the American College of Sports Medicine guidelines. Each session consisted of a warm-up, three exercise sequences, and a cool-down. One exercise sequence comprised one set of sit-to-stand repetitions followed by one set of double-leg heel raises. Thus, sit-to-stand and heel-raise repetitions were counted separately rather than as a single combined repetition. Participants were instructed to obtain adequate rest and to refrain from strenuous exercise or heavy physical activity before each training and assessment session.

Preparation and warm-up

Participants were instructed to avoid strenuous exercise before each session and to wear sports clothing and barefoot. Before the first training session, the researcher demonstrated the correct technique for both exercises. Blood pressure, heart rate, respiratory rate, body temperature, and peripheral oxygen saturation were measured 15 minutes before exercise. Participants then completed a standardized dynamic warm-up consisting of shoulder, trunk, hip, and knee flexion–extension; ankle dorsiflexion–plantar flexion; and ankle inversion–eversion. Each movement was performed for 10 seconds and repeated three times, followed by 1 minute of marching in place.

Sit-to-stand exercise

The sit-to-stand exercise was performed using a stable, armless chair with a seat height of approximately 45 cm. Participants began in an upright seated position with the hips fully supported on the chair, the knees flexed, and both feet placed flat and parallel on the floor approximately 10 cm behind the knees. The arms were crossed over the chest, and the gaze was directed forward. During the ascent phase, participants leaned the trunk slightly forward, pressed through the heels, and extended the knees and hips until reaching a fully upright standing position. During the descent phase, participants flexed the hips and knees and lowered the body under control until fully seated on the chair.

Heel-raise exercise

Immediately after completing each sit-to-stand set, participants performed the same number of double-leg heel raises. The starting position was upright standing with the feet parallel and the arms crossed over the chest. Participants raised both heels as high as possible to achieve their maximum comfortable plantar-flexion range while maintaining support through the metatarsophalangeal joints. The maximal heel-raised position was held for 2 seconds, after which the heels were lowered under control until they contacted the floor. External support was not used unless required for safety.

Cadence

Exercise cadence was controlled using a metronome set at 30 beats/min, corresponding to one beat every 2 seconds. Participants changed movement phase at each metronome beat. For the sit-to-stand exercise, the ascent and descent phases were each performed over approximately 2 seconds. For the heel raise, participants raised their heels over approximately 2 seconds, maintained the highest position for 2 seconds, and lowered their heels over approximately 2 seconds.

Volume and progression

Each training session included three sets of sit-to-

stand exercise and three sets of double-leg heel raises. The number of repetitions was increased according to a predetermined time-based progression: 8 repetitions per set during weeks 1–2, 10 repetitions during weeks 3–4, 13 repetitions during weeks 5–6, and 15 repetitions during weeks 7–8. Progression was determined by the intervention week and was not individualized according to participant performance. A participant progressed to the next training volume provided that the current volume could be completed without meeting any prespecified termination criterion.

Cool-down and monitoring

After completing the exercise, participants performed a standardized cool-down consisting of hamstring, quadriceps, calf, arm and shoulder, and spinal-rotation stretches, followed by deep breathing and relaxation. Each activity was performed for 30 seconds. Blood pressure, heart rate, respiratory rate, body temperature, and peripheral oxygen saturation were reassessed 15 minutes after the exercise. Heart rate and oxygen saturation were also monitored during training using a fingertip pulse oximeter.

Supervision and missed sessions

The intervention group received repeated supervision, physiological monitoring, exercise demonstrations, and direct contact with the research team, whereas the control group did not receive an attention-matched activity. All sessions were supervised to ensure proper technique and safety. Participants in the control group did not receive the STS-HR exercise program and were instructed to maintain their usual daily activities throughout the 8-week study period. Both groups received the same general education regarding physical activity recommendations based on WHO guidelines. However, the educational intervention was not designed as an attention-matched control for the supervised exercise sessions.

Outcome Measures

The original protocol identified Y-Balance Test performance as the study outcome but did not prespecify a single primary endpoint. For the revised principal exploratory analysis, the bilateral mean modified composite reach score at week 8 was selected. This outcome selection and the baseline-adjusted ANCOVA were introduced during manuscript revision and were therefore not prospectively prespecified. Direction-specific, limb-specific, change-score, and within-group analyses were treated as secondary exploratory analyses.

Modified Y-Balance Test

A field-based modified Y-Balance Test was conducted barefoot in a designated 3×3-m area using three floor-mounted measuring tapes arranged in the anterior, posteromedial, and posterolateral directions and separated by 120°. Before testing, the assessor explained and demonstrated the procedure. Participants completed six familiarization trials for each limb in each direction, followed by three recorded trials after an adequate rest period.

Participants stood on the test limb with the most distal aspect of the great toe positioned at the center of the grid. While maintaining single-leg stance, they reached as far as possible with the contralateral limb, lightly touched the measuring surface, and returned to the starting position under control. Testing was conducted in the following order: right anterior, left anterior, right posteromedial, left posteromedial, right posterolateral, and left posterolateral. The same order was used at baseline and follow-up.

A trial was considered invalid and repeated if the participant moved the stance foot or placed the reaching foot on the floor for support. Limb length was measured separately for each side from the anterior superior iliac spine to the most distal aspect of the medial malleolus while the participant was supine.

The bilateral mean modified composite score was calculated as the mean of the right- and left-limb modified composite scores. Higher values indicated better test performance. Because the mean rather than the maximum reach distance was used, this outcome differs from the standard YBT composite score and is therefore described as a modified composite reach score. All assessments were conducted by the same trained assessor using a standardized procedure. No study-specific intra-rater or inter-rater reliability assessment was conducted.

Other measurements

Age, height, body weight, BMI, limb length, leg dominance, baseline physical activity, and baseline dietary intake were recorded. Participants were also asked to document physical activity outside the intervention using activity diaries and dietary intake using food records. However, follow-up activity and dietary records were not quantitatively analyzed using a standardized scoring procedure. Therefore, the study could not determine reliably whether physical activity and dietary intake outside the intervention remained comparable between groups during follow-up. Baseline caloric intake, which was available from the baseline dietary assessment, was

included as a covariate in the revised exploratory ANCOVA. The unquantified follow-up activity and dietary records were not included in the model.

Statistical analysis

Baseline continuous characteristics were compared using independent-samples t-tests for approximately normally distributed variables and Mann–Whitney U tests otherwise. Baseline p-values were presented for descriptive and exploratory purposes only and were not used to determine whether randomization was successful, establish the absence of confounding, or select covariates. The revised principal exploratory analysis used ANCOVA to estimate the between-group difference in the week-8 bilateral mean modified composite reach score. Treatment group was entered as the fixed factor, with baseline bilateral mean modified composite score and baseline caloric intake entered as covariates. The treatment contrast was defined as STS-HR minus control, such that a positive estimate indicated a higher week-8 score in the STS-HR group. The adjusted between-group mean difference was reported in percentage points with its 95% CI, F statistic, p-value, and partial η^2.

Within-group comparisons were performed using paired-samples t-tests when individual change scores were approximately normally distributed and Wilcoxon signed-rank tests otherwise. For paired-samples t-tests, standardized within-group changes were reported as Cohen's, calculated as the mean individual change divided by the SD of the individual change scores. For Wilcoxon signed-rank tests, matched-pairs rank-biserial correlations were reported.

Unadjusted between-group comparisons of change scores were reported as mean differences with 95% CIs. Standardized between-group effects were expressed as Hedges', calculated using the pooled SD of the individual change scores with a small-sample bias correction. The contrast was consistently defined as STS-HR minus control, so positive values favored the STS-HR group. Direction-specific, limb-specific, change-score, and within-group analyses were considered secondary and exploratory. No adjustment for multiple testing was applied; therefore, the corresponding p-values were interpreted descriptively. All tests were two-sided, with $p<0.05$ used as the nominal significance threshold. Exact p-values were reported to three decimal places, except values below 0.001, which were reported as $p<0.001$.

Ethical considerations and trial registration

The study protocol was approved by the Institutional Ethics Committee of the Faculty of Medicine, Universitas Airlangga (Approval No. 206/EC/KEPK/FKUA/2025). The protocol was not published before participant enrollment and is available from the corresponding author upon reasonable request. A separate publicly available statistical analysis plan was not prepared. Permission to conduct the study was also obtained from the participating school prior to recruitment. Because all participants were minors, written informed consent was obtained from their parents or legal guardians, while written assent was obtained from each participant before enrollment. Confidentiality was maintained by assigning anonymous identification codes, and participants were free to withdraw from the study at any stage without penalty. All exercise sessions were supervised by trained physiotherapists to ensure participant safety throughout the intervention.

RESULTS

The results of this study are presented in three sections: baseline characteristics, within-group changes, and between-group comparisons of dynamic balance performance. All 15 intervention participants completed all 24 prescribed sessions, an adherence rate of 100%. No sessions were missed, no protocol deviations or withdrawals occurred, and no adverse events were observed or reported.

At baseline, total physical activity was 328.27 ± 179.67 MET-min/week in the control group and 346.87 ± 154.42 MET-min/week in the intervention group. Baseline energy intake was 1,947.64 ± 242.92 and 1,965.83 ± 239.39 kcal/day, respectively. Fat intake was 71.69 ± 16.68 versus 71.91 ± 20.77 g/day, carbohydrate intake was 280.34 ± 57.96 versus 276.38 ± 48.95 g/day, and protein intake was 52.76 ± 13.94 versus 52.50 ± 11.89 g/day. These baseline values are presented descriptively in Table 1.

Baseline demographic, anthropometric, physical activity, and dietary characteristics are summarized descriptively in Table 1. The study included 15 participants in each group, and all participants were right-leg dominant. Participants had low baseline physical activity levels, with mean values of 328.27 ± 179.67 MET-min/week in the control group and 346.87 ± 154.42 MET-min/week in the STS-HR group. Because this was a randomized trial, no hypothesis tests were used to assess baseline balance between groups. Potential baseline differences in the primary outcome were addressed through baseline-adjusted ANCOVA.

Within-group analysis (Table 2) showed no significant changes in the control group across all Y-Balance Test directions and limbs ($p > 0.05$), with small effect sizes indicating minimal change. In contrast, the intervention

TABLE 1. Baseline Characteristics, Physical Activity and Dietary Intake During the 8-Week Study Period.

Variable	Control Group (n=15)	Intervention Group (n=15)	p-value
Age (years)	16 (1.0) *	15 (0.5) *	0.106[a]
Height (cm)	164 (2.0) *	168 (5.0) *	0.649[a]
Body Weight (kg)	63.27 ± 16.44	61.47 ± 11.62	0.132[b]
Body Mass Index (kg/m²)	22.75 ± 4.81	22.02 ± 3.85	0.962[b]
Leg Length (cm)	88.93 ± 5.47	88.33 ± 5.58	0.727[b]
Physical Activity (METs)	328.27 ± 179.67	346.87 ± 154.42	0.543[b]
Right-leg dominance	15 (100%)	15 (100%)	–
Energy Intake (kcal)	1,947.64 ± 242.86	1,965.82 ± 239.38	0.880[b]
Protein Intake (g)	52.76 ± 13.93	52.49 ± 11.89	0.746[b]
Fat Intake (g)	71.69 ± 16.67	71.91 ± 20.76	0.966[b]
Carbohydrate Intake (g)	280.34 ± 57.96	276.38 ± 48.94	0.841[b]

Notes: Values are presented as mean ± SD, median (IQR), or n (%), as appropriate. BMI, body mass index; MET-min/week, metabolic equivalent minutes per week; SD, standard deviation.
a Mann Whitney U test; b Independent-samples t-test

TABLE 2. Within-Group comparison of dynamic balance function using the y-balance test after 8 weeks.

Group	Direction	Side	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	p-value	Effect Size
Control	Anterior	Right	57.22 ± 6.18	58.27 ± 6.77	0.532	0.165 (dz)
		Left	59.78 ± 8.12	58.29 ± 6.62	0.467	-0.193 (dz)
	Postero-lateral	Right	74.53 ± 11.74	76.07 ± 8.63	0.454	0.205 (dz)
		Left	74.87 ± 14.71	76.84 ± 8.69	0.479	0.188 (dz)
	Postero-medial	Right	82.96 ± 10.88	84.18 ± 7.21	0.690	0.105 (dz)
		Left	81.33 ± 9.94	83.02 ± 8.48	0.423	0.213 (dz)
	Composite Reach Length (%)	Right	80.70 ± 9.61	82.10 ± 7.49	0.577	0.156 (dz)
		Left	81.20 ± 11.04	81.91 ± 8.08	0.721	0.090 (dz)
Intervention	Anterior	Right	59.82 ± 5.68	66.40 ± 4.65	0.001	2.413 (dz)
		Left	59.73 ± 6.45	67.98 ± 3.88	0.001	1.643 (dz)
	Postero-lateral	Right	76.53 ± 9.82	88.09 ± 9.96	0.001	1.699 (dz)
		Left	78.07 ± 11.64	90.38 ± 8.30	0.001	1.503 (dz)
	Postero-medial	Right	83.07 ± 11.53	96.20 ± 7.90	0.001	1.565 (dz)
		Left	84.96 ± 10.88	97.51 ± 8.46	0.001	1.566 (dz)
	Composite Reach Length (%)	Right	82.91 ± 9.61	94.62 ± 6.72	0.001	2.161 (dz)
		Left	84.32 ± 9.94	96.71 ± 6.35	0.001	1.997 (dz)

Note: Within-group effect sizes were calculated as Cohen's (dz), using the standard deviation of the individual paired change scores as the denominator. For the non-normally distributed outcome analyzed using the Wilcoxon signed-rank test, the matched-pairs rank-biserial correlation (rrb)was reported instead.

group demonstrated significant improvements in all directions and both limbs (p = 0.001), accompanied by large effect sizes (d > 0.8). Notable gains in composite reach length reflect enhanced postural control and lower limb neuromuscular function, supporting the effectiveness of the sit-to-stand and heel-raise intervention.

In the unadjusted analysis of change scores (Table 3), the STS-HR group demonstrated greater improvements than the control group in all direction-specific Y-Balance Test outcomes. The between-group mean difference in change was 6.17 points for the right anterior direction (95% CI 2.46 to 9.88; p = 0.006; Hedges' g = 1.108) and 9.73 points for the left anterior direction (95% CI 4.83 to 14.63; p < 0.001; Hedges' g = 1.456). Corresponding differences were 10.02 points for the right posterolateral direction (95% CI 3.71 to 16.34; p = 0.006; Hedges' g = 1.067), 10.34 points for the left posterolateral direction (95% CI 3.27 to 17.41; p = 0.006; Hedges' g = 1.067), 11.91 points for the right posteromedial direction (95% CI 4.30 to 19.52; p = 0.003; Hedges' g = 1.144), and 10.87 points for the left posteromedial direction (95% CI 4.91 to 16.83; p = 0.001; Hedges' g = 1.326). These estimates were unadjusted for baseline scores and should be interpreted as exploratory. For the dominant/right-limb composite reach length, the mean change was 1.40 ± 9.16 percentage points in the control group and 11.72 ± 5.48 percentage points in the STS-HR group. The unadjusted between-group mean difference in change was 10.32 percentage points (95% CI 4.62 to 16.02; p = 0.001), corresponding to a large standardized effect (Hedges' g = 1.33). For the left-limb composite reach length, the mean change was 0.07 ± 7.90 percentage points in the control group and 12.51 ± 6.17 percentage points in the STS-HR group, yielding an unadjusted mean difference of 12.44 percentage points (95% CI 7.12 to 17.76; p < 0.001; Hedges' g = 1.71). The left-limb analysis was considered exploratory.

After adjustment for baseline bilateral composite score and caloric intake, the STS-HR group had a higher bilateral mean composite Y-Balance Test score at week 8 than the control group. The adjusted between-group mean difference was 12.4 percentage points (95% CI 8.6 to 16.1; $F(1,26) = 46.675$; p < 0.001; partial $\eta^2 = 0.642$). Baseline composite score was also independently associated with the week-8 outcome ($F(1,26) = 28.068$; p < 0.001; partial $\eta^2 = 0.519$), whereas caloric intake was not ($F(1,26) = 0.106$; p = 0.747; partial $\eta^2 = 0.004$).

Safety and exercise perception

Exercise intensity was monitored using the Borg 6–20 Rating of Perceived Exertion scale. The recorded session-level RPE values ranged from 9 to 11, corresponding to very light to light perceived exertion. The RPE value remained at 9 during sessions 1–6, increased to 10 during sessions 7–18, and reached 11 from session 19 onward. These values were summarized descriptively because no

TABLE 3. Unadjusted between-group comparison of change scores in dynamic balance performance after 8 Weeks.

YBT outcome	Mean change control	Mean change STS-HR	Unadjusted mean difference (95% CI)	p-value	Hedges' g
Anterior right	1.40 ± 6.31	6.58 ± 2.73	6.17 (2.46 to 9.88)	0.006	1.24
Anterior left	−1.49 ± 7.70	8.24 ± 5.02	9.73 (4.83 to 14.63)	0.001	1.46
Posterolateral right	1.53 ± 9.75	11.56 ± 6.80	10.02 (3.71 to 16.34)	0.006	1.16
Posterolateral left	1.98 ± 10.52	12.31 ± 8.19	10.34 (3.27 to 17.41)	0.006	1.07
Posteromedial right	1.22 ± 11.61	13.13 ± 8.39	11.91 (4.30 to 19.52)	0.003	1.14
Posteromedial left	1.69 ± 7.92	12.56 ± 8.02	10.87 (4.91 to 16.83)	0.001	1.33
Composite reach length right	1.40 ± 9.16	11.72 ± 5.48	10.32 (4.62 to 16.02)	0.001	1.33
Composite reach length left	0.07 ± 7.90	12.51 ± 6.17	12.44 (7.12 to 17.76)	0.001	1.71

Note: Values are presented as mean change ± SD, where change was calculated as the week-8 value minus the baseline value. Unadjusted mean differences were calculated as the change in the STS-HR group minus the change in the control group; therefore, positive values favor the STS-HR group. Standardized between-group effect sizes were calculated as Hedges' g using the pooled standard deviation of the individual change scores and a small-sample correction.

TABLE 4. Baseline- and calorie-adjusted ANCOVA for bilateral mean composite Y-Balance Test score at week 8.

Predictor	Adjusted estimate (95% CI)	F (df)	p-value	Partial η^2
STS-HR vs control	12.4 (8.6 to 16.1) percentage points	46.675 (1, 26)	<0.001	0.642
Baseline bilateral composite score	0.490 (0.300 to 0.680)	28.068 (1, 26)	<0.001	0.519
Caloric intake	approximately 0.000	0.106 (1, 26)	0.747	0.004

Note: The group estimate represents the intervention group minus the control group. Positive values favor the STS-HR group. The outcome was expressed as a percentage; regression coefficients originally generated on the proportion scale were multiplied by 100 for reporting. Partial η^2 was calculated from the Type III F statistic and residual degrees of freedom.

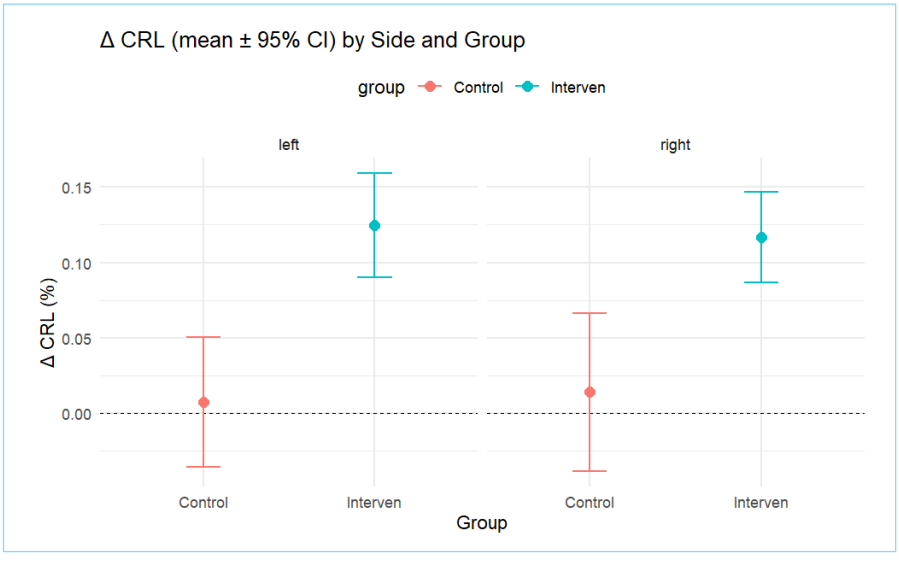


Fig 1. Mean Change in Composite Reach Length (ΔCRL%) with 95% Confidence Intervals by Group and Limb
Mean changes in composite reach length (ΔCRL%) for the control and intervention groups are presented for both left and right limbs. Error bars represent 95% confidence intervals. The dashed horizontal line indicates no change (Δ = 0).

inferential analysis of RPE was prespecified. Therefore, variations in RPE should not be interpreted as evidence of physiological adaptation or improved exercise tolerance. In addition, RPE alone cannot establish the safety or broader feasibility of the intervention.

BORG Rating of Perceived Exertion (RPE) scores across 24 training sessions over 8 weeks. The training program was progressively increased in repetitions: weeks 1–2 (8 repetitions), weeks 3–4 (10 repetitions), weeks 5–6 (13 repetitions), and weeks 7–8 (15 repetitions). Fig 2 illustrates the recorded perceived exercise intensity throughout the 8-week intervention. Perceived exertion was assessed using the Borg 6–20 Rating of Perceived Exertion scale. The recorded RPE values ranged from

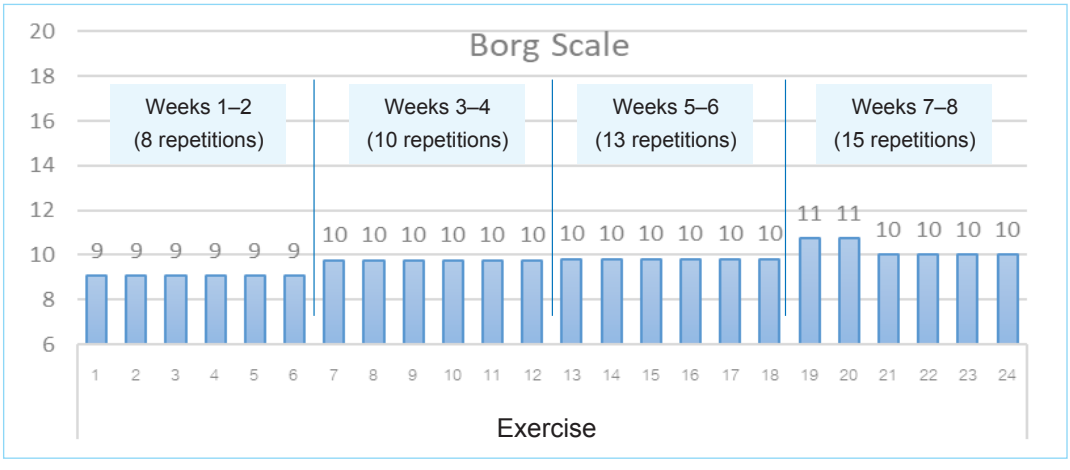


Fig 2. Session-specific Rating of Perceived Exertion during the intervention. RPE was assessed using the Borg 6–20 scale. Values of 9–11 correspond to very light to light perceived exertion. Data are presented as mean±SD for each session.

9 to 11, corresponding to very light to light perceived exertion. The RPE value remained at 9 during sessions 1–6, increased to 10 during sessions 7–18, and reached 11 during sessions 19–20. These values are presented descriptively and should not be interpreted as evidence of physiological adaptation or improved exercise tolerance. Small variations in the recorded RPE values across sessions were interpreted descriptively and were not used to infer physiological adaptation. Pain levels were assessed using the Wong–Baker Scale across 24 training sessions over 8 weeks. All participants consistently reported a pain score of 0 throughout the intervention period.

Fig 3 shows that no participants reported pain during the 8-week intervention, with Wong–Baker scores consistently at 0 across all sessions. This indicates that the sit-to-stand and heel-raise program was well tolerated and did not induce musculoskeletal discomfort despite progressive loading. No pain was reported during the monitored sessions. However, the small number of exposed participants and short follow-up preclude definitive conclusions regarding safety.

Participants' perception of the exercise program

At the end of the intervention, all participants in the intervention group (n = 15) completed a perception questionnaire consisting of four Likert-scale statements. Overall, participants reported highly positive perceptions of the exercise program. A total of 53% strongly agreed and 40% agreed that the intervention was beneficial, while only 7% expressed uncertainty. Regarding ease of implementation and independence, 67% of participants strongly agreed and 33% agreed that the exercises were simple and could be performed independently. In terms of safety, the majority of participants perceived the intervention as safe, with 73% strongly agreeing and 27% agreeing that the exercises did not cause serious adverse effects. Notably, 40% of participants strongly agreed and 27% agreed that they were willing to continue the exercise after the study, although 33% remained uncertain. Importantly, no participants reported disagreement or strong disagreement across any of the statements. Participants reported high acceptability, perceived safety, and ease of performing the intervention. However, willingness to continue the exercise was less consistent, with 67% agreeing or strongly agreeing and 33% remaining uncertain.

DISCUSSION

The absence of significant changes in the control group indicates that dynamic balance in sedentary male adolescents remains relatively stable in the absence of specific training stimuli. This finding suggests that time alone (8 weeks) is insufficient to induce neuromuscular adaptations that meaningfully affect balance performance. This result is consistent with previous studies, such as Hoch et al.[22], which reported no significant changes in Y-Balance Test (YBT) scores following a period of routine activity without targeted intervention, and Linek et al.[25], who demonstrated high reliability of YBT measurements (ICC > 0.85) in the absence of structured training. Therefore, the lack of improvement in the control group reinforces the notion that the postural control system in adolescents requires specific and targeted stimuli to improve. Furthermore, this finding supports the internal validity of the study by confirming that improvements observed in the intervention group are not attributable to measurement variability or learning effects. Conceptually, this highlights that general physical activity without a structured balance component is insufficient to produce significant improvements in postural control.

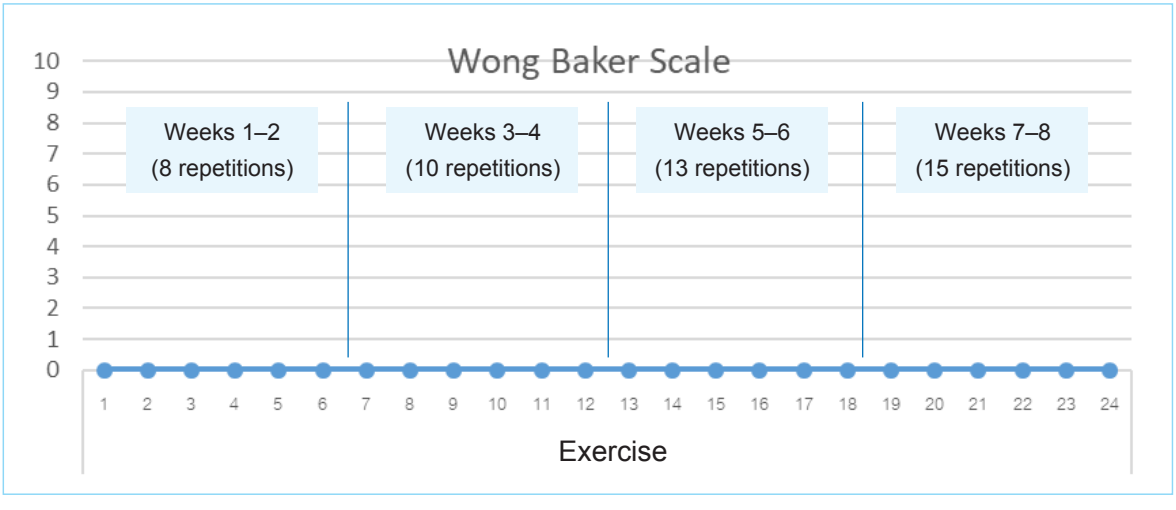


Fig 3. Pain Assessment Using the Wong–Baker Scale Across Training Sessions

Mechanisms underlying the effectiveness of STS-HR training

The significant improvements observed in the intervention group can be explained by neuromuscular adaptations involving enhanced muscle strength, motor coordination, and sensorimotor integration. The sit-to-stand (STS) component primarily activates large extensor muscle groups, such as the quadriceps and gluteal muscles, which are essential for controlling vertical movement and stabilizing the center of mass. Meanwhile, the heel-raise (HR) component specifically targets the plantar-flexor muscles (gastrocnemius–soleus complex), which play a critical role in maintaining postural stability during dynamic tasks. The integration of these two functional movements creates a training stimulus that closely resembles daily activities, thereby improving the efficiency of dynamic postural control. These findings are consistent with Lizama-Pérez et al.[14], who reported improvements in muscle strength (29–38%) and muscle quality (up to 45%) following STS training, and with Muehlbauer et al.[24], who demonstrated significant improvements in YBT performance after structured balance training. Moreover, the improvements observed across all reach directions (anterior, posteromedial, and posterolateral) indicate that the adaptations were global rather than direction-specific. This suggests that STS-HR training enhances not only localized muscle strength but also the coordination between multiple body segments required for maintaining dynamic stability.

Role of Proprioception and Sensorimotor Efficiency

In addition to strength gains, the observed improvements may also be attributed to enhanced proprioceptive sensitivity and more efficient sensorimotor integration. Repetitive functional movements such as STS-HR provide continuous stimulation to proprioceptive receptors in muscles and joints, thereby improving the nervous system's ability to detect body position and respond to balance perturbations. Linek et al.[25] emphasized that improvements in YBT performance are closely associated with enhanced control of the center of gravity and improved neuromuscular coordination. Furthermore, Borgmann et al.[26] demonstrated that reductions in YBT performance are primarily associated with lower limb muscle fatigue, suggesting that improvements observed in this study may also reflect enhanced neuromuscular endurance. In this context, STS-HR training appears to improve not only force production capacity but also the efficiency of energy utilization during postural control. This dual adaptation likely explains the large effect sizes and consistent improvements observed among participants. Such adaptations are particularly relevant in sedentary individuals, who typically exhibit deficits in sensorimotor control.

Magnitude of between-group differences

The STS-HR group demonstrated a sizable improvement in Y-Balance Test performance compared with the control group. After adjustment for baseline bilateral composite score and caloric intake, the between-group difference in the bilateral mean modified composite reach score was 12.4 percentage points (95% CI 8.6 to 16.1; $p<0.001$). However, because an established minimal important difference for this modified outcome in sedentary male adolescents is unavailable, the clinical importance of the observed difference remains uncertain. The low baseline physical activity level of the participants may have provided greater opportunity for improvement, although this explanation was not directly tested. Ortega et al.[27] noted that MET values below 12 reflect suboptimal aerobic fitness, which is associated with impaired postural function. Under such conditions, even relatively simple interventions can produce substantial functional gains. Additionally, the progressive overload applied in the training protocol likely facilitated gradual adaptation without inducing excessive fatigue. This is supported by Schedler et al.[20], who demonstrated that increased training volume significantly improves YBT performance. Therefore, the large effect sizes observed in this study reflect both the responsiveness of the sedentary population and the effectiveness of the intervention design.

Safety and adherence of the STS-HR intervention

Complete attendance and the absence of observed adverse events indicate that the intervention was well tolerated by the 15 participants who received it. However, the small number of exposed participants and the short intervention period preclude definitive conclusions regarding safety. This can be attributed to the nature of the exercises, which are classified as closed-chain, bodyweight-based movements that promote stable load distribution and reduce injury risk. Lizama-Pérez et al.[14] similarly reported no adverse effects associated with STS training in sedentary populations. Moreover, the exercise intensity remained within a light-to-moderate range (Borg scale 9–11), allowing for physiological adaptation without excessive fatigue. Borgmann et al.[26] further emphasized that impairments in balance performance are more commonly associated with high-intensity fatigue rather than moderate, repetitive training. The simplicity of the STS-HR protocol, requiring no specialized equipment and closely resembling daily movements, likely contributed

to both its safety and high participant acceptance. These findings suggest that STS-HR training is not only effective but also highly feasible for implementation in school-based or community settings.

Implications of the study

This study provides preliminary evidence that an 8-week sit-to-stand and heel-raise intervention can improve Y-Balance Test performance in sedentary male adolescents. Because the exercises require minimal equipment, the program may be practical for supervised implementation in school or community settings. However, the present study did not measure muscle strength, neuromuscular adaptation, functional decline, or lower-extremity injury incidence. Therefore, the findings should not be interpreted as evidence that the intervention prevents functional decline or injury. Whether improvements in Y-Balance Test performance translate into broader functional benefits or a lower risk of injury should be examined in larger and longer-term trials that directly measure these outcomes.

Limitations of the study

The findings are limited to a small sample of sedentary male adolescents from a single Catholic senior high school in Surabaya who were required to maintain a one-leg stance for more than 10 seconds. The exclusion of female adolescents, the single-school setting, specific selection criteria, and local educational and cultural context limit generalizability to broader adolescent populations.

Because the stored dataset contained the average rather than the maximum of the three reach trials, the scores could not be recalculated using the standard YBT scoring method. This deviation may limit comparability with published normative and composite YBT values.

The study was not prospectively registered, and a publicly accessible statistical analysis plan was unavailable before participant enrollment. Consequently, prospective verification of the prespecified primary outcome and analytical decisions is not possible, which increases the risk of selective outcome reporting. The results should therefore be interpreted with appropriate caution.

Several limitations should be considered when interpreting the adjusted analysis. Formal diagnostic testing of the ANCOVA assumptions, including linearity between the covariates and outcome, homogeneity of regression slopes, normality and homoscedasticity of residuals, and the absence of influential observations, was not performed. Consequently, it cannot be confirmed that all model assumptions were satisfied. Violations of these assumptions could affect the validity of the estimated adjusted between-group difference, its confidence interval, and the corresponding significance test. The ANCOVA findings should therefore be regarded as exploratory and interpreted cautiously.

CONCLUSIONS

This study demonstrates that an 8-week sit-to-stand and heel-raise (STS-HR) program significantly improves dynamic balance in sedentary male adolescents. Consistent improvements across all Y-Balance Test directions, along with large effect sizes, indicate clinically meaningful functional gains. These effects are likely driven by enhanced neuromuscular coordination, lower limb strength, and sensorimotor integration. The lack of change in the control group confirms that improvements were attributable to the intervention. The program was safe and feasible, with full adherence and no adverse events. Overall, the 8-week STS-HR program improved Y-Balance Test performance in the sedentary male adolescents included in this study. Its effects on functional decline, daily physical functioning, and lower-extremity injury risk remain unknown and require investigation in larger, longer-term trials.

Data Availability Statement

The data supporting the findings of this study are not publicly available due to ethical and privacy considerations involving human participants. However, the data are available from the corresponding author upon reasonable request and with permission from the institutional ethics committee.

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DECLARATIONS

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Conflict of Interest

All authors declare no conflict of interest in this research.

Registration Number of Clinical Trial

This trial was not prospectively registered in a publicly accessible clinical trial registry before participant enrollment. The authors acknowledge this omission as a limitation of the study.

Author Contributions

Conceptualization and methodology, F.F., I.P.A.P., and Y.D.P.; Investigation, F.F.; Formal analysis, F.F., I.P.A.P., and A.; Visualization and writing – original draft, F.F.; Writing – review and editing, F.F., I.P.A.P., Y.D.P., and A.; Supervision, I.P.A.P. and Y.D.P. All authors have read and agreed to the final version of the manuscript.

Use of Artificial Intelligence

Artificial intelligence tools (ChatGPT 5.2 and Grammarly) were used only for language editing and proofreading; all scientific content, analysis, and interpretations were developed by the authors.

Institutional Review Board Statement

The study protocol was approved by the Institutional Ethics Committee of the Faculty of Medicine, Universitas Airlangga (Approval No. 206/EC/KEPK/FKUA/2025).

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